NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

October 1941 as
Advance Restricted Report

DEVELOPMENT OF COWLING FOR LONG-NOSE AIR-COOLED ENGINE IN THE NACA FULL-SCALE WIND TUNNEL

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WASHINGTON

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INTRODUCTION

An investigation of cowlings for long-nose radial engines has been made on the Curtiss XP-42 airplane in the NACA full-scale wind tunnel. The XP-42 airplane is provided with a Pratt & Whitney R-1830-31 engine, which has a propeller shaft and bearing housing that is 20 inches longer than the standard short-nose engine of the same series. This forward extension of the propeller enables the use of fuselage nose shapes of higher fineness ratio than are possible with the blunter short-nose engine. In the original Curtiss Company design of the XP-42 airplane the pointed fuselage nose was used (fig. 1) and sharp-edge scoops were added at the bottom and top of the cowling for the engine-cooling and the carburetor-air inlets. Flight tests showed the high speed of the airplane to be comparable with, but not superior to, that of the P-36, which is a similar airplane with a short-nose engine and a conventional NACA cowling installation. Inspection of the cowling scoops disclosed sources of drag, the existence of which were substantiated by preliminary NACA flight measurements. These tests showed that the engine cooling air entered the lower scoop at about half the airplane flight velocity and that the kinetic energy of this flow was dissipated by the sharp change in the air-flow direction at the rear of the scoop and by the expansion from the small scoop area to large area ahead of the engine. (See fig. 2.)

The existence of a large internal energy loss due to the cooling-air flow was established and experience led to the belief that a further substantial external drag would be added by the flow over the sharp scoop edges. The full-scale tunnel investigation was then instigated for the purpose of improving the original scoop cowling or developing an efficient cowl of another type.

The wind-tunnel program included an initial investigation of the original P-42 cowling, which was followed

by tests of several modified arrangements with improved scoops. The general unsatisfactory aerodynamic characteristics of all the cowlings with scoop inlets led to the development of the annular high-velocity inlet cowling. Since it was the purpose of the wind-tunnel investigation to develop an optimum cowling that could be later constructed for flight tests, the various cowling parameters, such as inlet velocity ratio, exit area, etc., were studied in considerable detail. This cowling has been constructed and is currently undergoing flight tests on the P-42 airplane. The results of the flight investigation will be reported at a later date.

METHOD AND APPARATUS

The NACA full-scale wind-tunnel balance equipment used for the force measurements is described in reference 1. The method of mounting the airplane on the balance is shown in figure 1. The special technique and apparatus used for the momentum measurements are described in reference 2. Static-pressure measurements were obtained either by the use of static orifices or 1/16-inch diameter static-pressure tubes mounted near the airplane surfaces. The air flow through the engine cowling was measured by total-pressure and static-pressure tubes placed in the diffusers ahead of the engine baffles, and in the cowl outlets.

RESULTS AND DISCUSSIONS

Original XP-42 cowling.- A photograph of the installation of the original scoop cowling on the XP-42 airplane is shown in figure 1; a sketch with a more detailed view of the engine air scoop is shown in figure 2. The cooling air is turned with a short radius through 90° and discharged into the compartment ahead of the engine cylinders. As a result of the energy losses occurring in the turn and the expansion, the total pressure at the front of the engine baffles was found to be only about 0.4 the free-stream total pressure. This large inlet loss was chiefly responsible for the high drag of the cowling installation and the drag coefficient for the airplane equipped with the original cooling-air scoop was 0.0040 higher than for

the smooth airplane with the scoop removed and the cowling sealed. Although the internal losses largely accounted for the drag of the original cowl, a substantial increment was also added by the sharp scoop edges. The drag coefficient for the airplane in the smooth condition (fig. 3) served as a base value for determining the drags of all the modifications tested.

Original cowling with multiple scoops.- In order to avoid the large internal cowl losses, the single original sharp-edge scoop was replaced with four smaller rounded inlet scoops (fig. 4). The use of multiple scoops rather than a single scoop was advantageous both in obtaining better diffuser passages and in avoiding the sharp bend required in the single-scoop arrangement. A sketch showing the detailed dimensions of the ducts is contained in figure 5(a). The results obtained with this arrangement, which was designated cowl 1, are shown in table I.

The results were unsatisfactory since it was found that the flow was separating from the inner wall of the duct passages and owing to the negative pressures over the top of the cowl in the climb condition, the flow through the upper scoop was reversed. As a result of the flow breakdown in the ducts, the pressure in front of the engine averaged only about 0.6 the free-stream pressure (fig. 6). The air-flow quantities measured for three exit areas of 67, 84, and 98 square inches were 6,970, 8,810, and 10,280 cubic feet per minute, respectively. The drag coefficient corresponding to the 67-square-inch outlet area was 0.0023. The drag of the airplane with the scoop outlets sealed and with the inlets unsealed was increased 0.0017 above the drag of the smooth airplane.

As a result of the difficulties encountered with the four-scoop arrangement, the top scoop was removed and the scoop inlets were extended forward along the cowl about 11 inches (see fig. 7); with these changes the duct inlet area was considerably reduced. (See fig. 5(b).) The modifications served to locate the inlet more nearly normal to the local flow direction and to lengthen the diffusing passage. The results were somewhat more satisfactory and the total pressures in front of the engine were higher than for the former arrangement. (See fig. 6.)

The diffuser passage, however, was still inefficient, since flow breakaway occurred on its inner wall and a further modification was made in which the duct passages were straightened. (See fig. 5(c).) For this improved arrangement, with an outlet area of 91 square inches, a drag coefficient increment of 0.0024 was measured with an air-flow quantity of 12,700 cubic feet per minute. With the scoop inlets and outlets sealed, the airplane drag coefficient was increased 0.0006, which is a measure of the effect of the protruding scoops on the external drag of the airplane.

Annular inlet cowl.- Since the drag of all the scoop arrangements tested was high, the investigation was directed toward developing a cowl in which the cooling air was introduced through a narrow annular inlet at the nose of the airplane, with a spinner fairing for the propeller hub and the blade shanks (figs. 8 and 9). This cowl, which is designated cowl 2 (table I), was designed so that the velocity at the cooling-air inlet was about one-fourth of the free-stream velocity. It was tested first with the exit sealed and the airplane drag was increased 0.0012, owing to the cowl form drag and the circulation of air in the cowl opening. With the inlet also sealed, the airplane drag was increased by only 0.0003. For different outlet areas, the airplane drag coefficient was increased 0.0022 with an air flow of 12,050 cubic feet per minute and was increased 0.0027 with an air flow of 17,000 cubic feet per minute.

These drag increments caused by air flow were too large and since drag reductions that should have been expected owing to improved internal flow (see fig. 6) were not fully realized, it was suspected that the cowl outlet was unsatisfactory. Tuft investigation of the flow from the original cowl outlet on the XP-42 airplane (fig. 10) showed that air was being discharged over and around the exhaust collector and flap gear in such a manner that the flow over the fuselage was disturbed. The outlet was modified, as shown in figure 10, by removing the conventional flap gear and exhaust collector from behind the engine and installing a smooth unrestricted outlet. With this modification, the drag coefficient was reduced 0.0007 and the cowl drag coefficient of 0.0015 was measured with a flow of 12,040 cubic feet per minute. The investigation was continued by sealing the conventional radial cowling outlet and providing a bottom outlet on the cowl. (See fig. 11(a).) This bottom outlet was too small because

the measured air flow was lower than required and a larger bottom outlet was constructed (fig. 11(b)). The cowl drag coefficient for this arrangement was 0.0011 with air flow of 12,800 cubic feet per minute. This drag is 0.0004 lower than for the cowling with the smooth radial outlet and is 0.0011 lower than the conventional flap outlet.

The large drag reductions effected with the improved outlets emphasize the importance of providing a smooth outlet on production airplanes. Although the single bottom outlet will probably be insufficient to provide uniform cooling for all the engine cylinders, the result obtained with this arrangement is of particular interest as a reference for evaluating the drag of the outlets.

From pressure measurements in the diffuser of the annular cowl 2 (fig. 6), it was noted that the total pressure was less than 0.9 the free-stream dynamic pressure. Since it was expected that this value would be close to stream pressure, the flow over the spinner was investigated with tufts. It was found that flow reversal was occurring on the upper part of the spinner at the inlet. This phenomenon was further investigated by measurements of pressures along the spinner, which are shown in figures 12 and 13. In these figures the magnitude of the pressure is indicated as the length of the vector normal to the spinner surface. It will be noted that a large adverse pressure gradient exists in the direction of air flow, the value of which is indicated by the slope of the pressure plots. For the climb condition the slope is high forward on the spinner and shows a jagged peak ahead of the cowl inlet. For the high-speed lift coefficient ($C_L = 0.150$) the adverse pressure gradient is high toward the forward part of the spinner and decreases several inches ahead of the nose of the inlet. In agreement with usual boundary-layer phenomena, the extent of tuft reversal could be coordinated with the slope of the pressure gradient along the spinner. Further modification was then made to cowl 2 (fig. 14) to reduce the pressure gradient along the spinner. The inlet area for the cowling was reduced by increasing the spinner size (spinner B, fig. 9) so that the inlet-velocity ratio (V_i/V) was increased above 0.5. With the higher inlet velocities, the diffuser pressures were increased to approximately $0.97q_0$. The pressures on the spinner corresponding to the two outlet conditions tested are shown in figures 15 and 16.

For the high-speed condition the rise in pressure along the modified spinner is considerably lower than for the original spinner. In the climb condition, the same irregularities in the pressure distribution occurred and these irregularities were found to be associated with a tuft reversal even for the higher inlet velocity obtained with the spinner modification. The pressures at the face of the engine in the climb condition were, however, uniform and high.

The drag coefficient for cowl 2 and spinner B, with the modified bottom outlet, was 0.0006 with an air flow of 13,870 cubic feet per minute. The gain due to increasing the inlet velocity and recovering the full total pressure in the diffuser amounted to 0.0005. The drag coefficient of 0.0006, measured for this arrangement, is the lowest that has been obtained in full-scale tunnel tests on radial-air-cooled engine cowlings. The efficiency of the cowl is most clearly demonstrated by the total-pressure measurements at the outlet (fig. 17). By progressive modifications the outlet total pressure was increased from an average of about $0.3q_0$ with cowl 1, to more than $0.8q_0$ with cowl 2 and spinner B. Since the internal drag losses are a direct function of the factor

$1 - \sqrt{\frac{H}{q_0}}$, increasing the value of H/q_0 at the outlet

from 0.3 to 0.8 corresponds to reducing the internal drag losses to almost one-fifth.

In order to determine whether the high efficiency of this cowl could be preserved with greater air flows, the outlet area was increased about 50 percent by partly opening the smooth radial outlet. A cowl drag coefficient of 0.0012 was measured with an air flow of 21,140 cubic feet per minute. This air flow is sufficient not only for the engine air but also for the carburetor and oil cooler. An investigation of ducts for handling the oil and the carburetor air was not made.

In order to aid in the estimation of the compressibility effects and to study the flow within the annular diffuser passages, pressure measurements were made over the inside and the outside of the cowl for several different air-flow conditions. These plots are shown in figures 18 to 21. The maximum negative pressure of approximately 0.4q was measured at the nose of the cowl, which

indicates that the critical compressibility speed will occur above 500 miles per hour at 20,000 feet altitude. The uniform recovery pressure on the inside of the duct is demonstrated in figures 19 and 21.

CONCLUSIONS

1. The long-nose engine enables the design of an efficient annular inlet cowling owing to the length available for a diffusing passage.

2. The ratio of the cooling-air velocity at the cowling inlet to the stream velocity is one of the most important design variables for the annular inlet cowling and this ratio should not be less than about 0.5.

3. The critical compressibility speed for the long-nose engine cowling can be extended to above 500 miles per hour at 20,000 feet altitude.

4. Important drag losses occur due to the flow of cooling air out of conventional cowling outlets with flap gear and exhaust collectors to disturb the flow.

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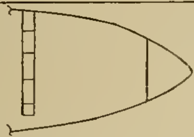
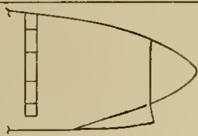
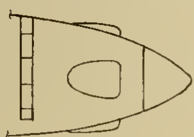
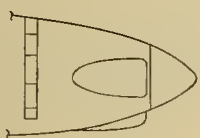
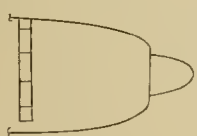
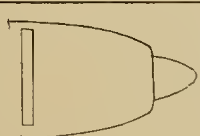
REFERENCES

1. DeFrance, Smith J.: The N.A.C.A. Full-Scale Wind Tunnel. Rep. No. 459, NACA, 1933.

2. Goett, Harry J.: Experimental Investigation of the Momentum Method for Determining Profile Drag. Rep. No. 660, NACA, 1939.

TABLE I. - SUMMARY OF RESULTS

Cowl	Sketch	Cooling system: Width outlet opening (in.)	Cooling system: Test conditions	Exit area (sq in.)	Drag coefficient (at 100 mph): $C_{D_{min}}$	Drag coefficient (at 100 mph): C_D at C_L=0.15	Drag coefficient (at 100 mph): ΔC_D at C_L=0.15 (b)	Air quantity (cu ft per min at 350 mph)	Inlet velocity ratio $\frac{V_1}{V}$
Smooth without original scoop		Sealed			0.0192	0.0203			
Smooth with original scoop		1.49	Standard	167	0.0232	0.0243	0.0040	16,100	0.69
Cowl 1		Sealed			0.0209	0.0220	0.0017		
		5/8		67	.0212	.0226	.0023	6,970	0.15
		3/4		84				8,810	.19
		7/8		98				10,280	.23
		Sealed	Oil cooler open		.0210	.0224	.0021		
Cowl 1 modified		Sealed	Scoops sealed		0.0194	0.0209	0.0006		
		5/8	" "		.0196	.0209	.0006		
		5/8	Scoops open	63	.0206	.0221	.0018	7,330	0.23
		3/4	" "		.0208	.0224	.0021		
		7/8	" "	98	.0210	.0225	.0022	10,900	.34
		5/8	Duct straightened, expansion reduced.	65	.0211	.0224	.0021	9,160	.28
		7/8	Same as 5/8	91	.0216	.0227	.0024	12,700	.39
Cowl 2 Spinner A		Sealed			0.0200	0.0215	0.0012		
		5/8		70	.0213	.0225	.0022	12,050	0.32
		3/4		78				13,750	.36
		7/8		98	.0216	.0230	.0027	17,000	.44
		Sealed	Oil cooler open		.0209	.0222	.0019		
		5/8	(a)	63	.0204	.0218	.0015	12,040	.31
		Sealed	Nose sealed [a]		.0192	.0206	.0003		
		"	Bottom exit open [a]	72	.0198	.0214	.0011	9,940	.26
		"	Modified bottom exit[a]	91	.0199	.0214	.0011	12,800	.33
		"	Modified bottom exit[a], upper inlet sealed.	91	.0199	.0212	.0009	13,550	.35
		Partial 5/8	Modified bottom exit[a]	136	.0202	.0216	.0013		
		" 5/8	Bottom sealed [a]	45				8,150	.21
		" 7/8	" " [a]	63				12,100	.32
		" 1-1/4	" " [a]	90	.0209	.0224	.0021	18,600	.49
Cowl 2 modified Spinner B		Sealed	Modified bottom [a]	91	0.0199	0.0209	0.0006	13,870	0.55
		Partial 5/8	" " [a]	131	.0204	.0215	.0012	21,140	.83

[a] Cowl flap gear removed and smooth exit installed.

[b] Based on smooth condition with original scoop off; landing gear fairing removed; control surfaces unsealed; and antenna on.

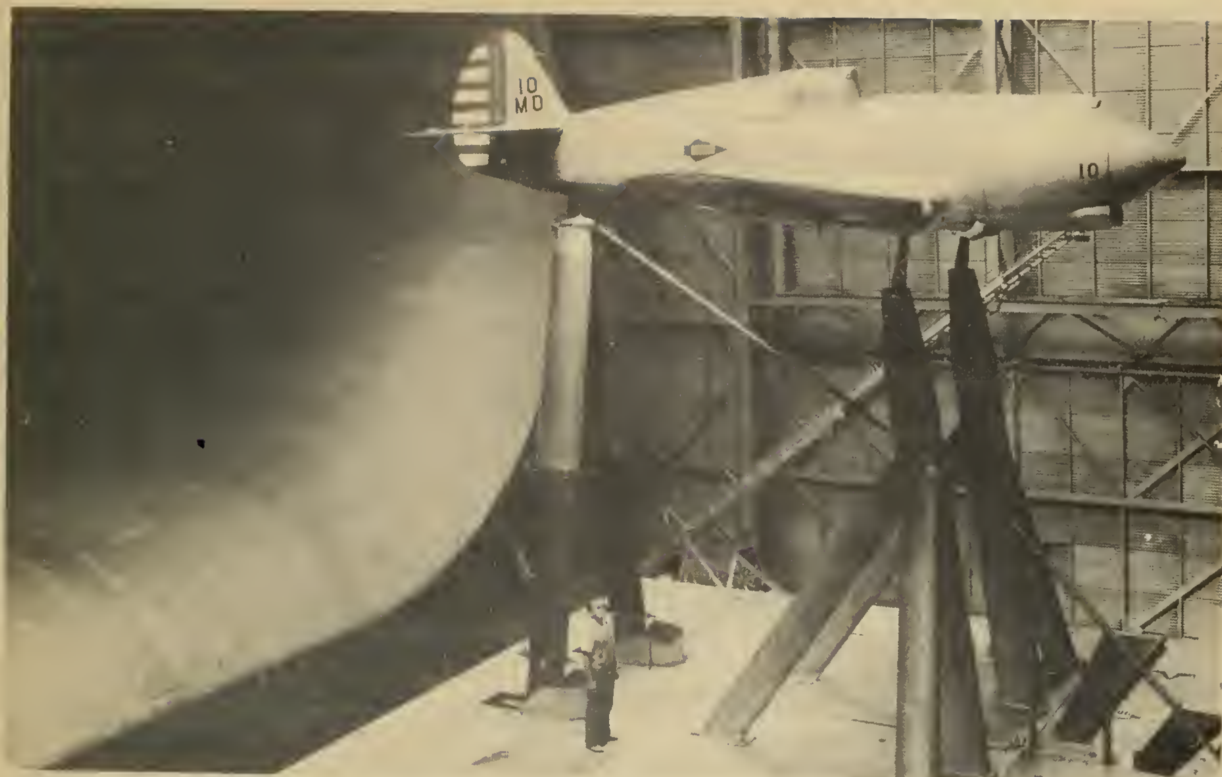


Figure 1.- The XP-42 airplane in the standard condition.

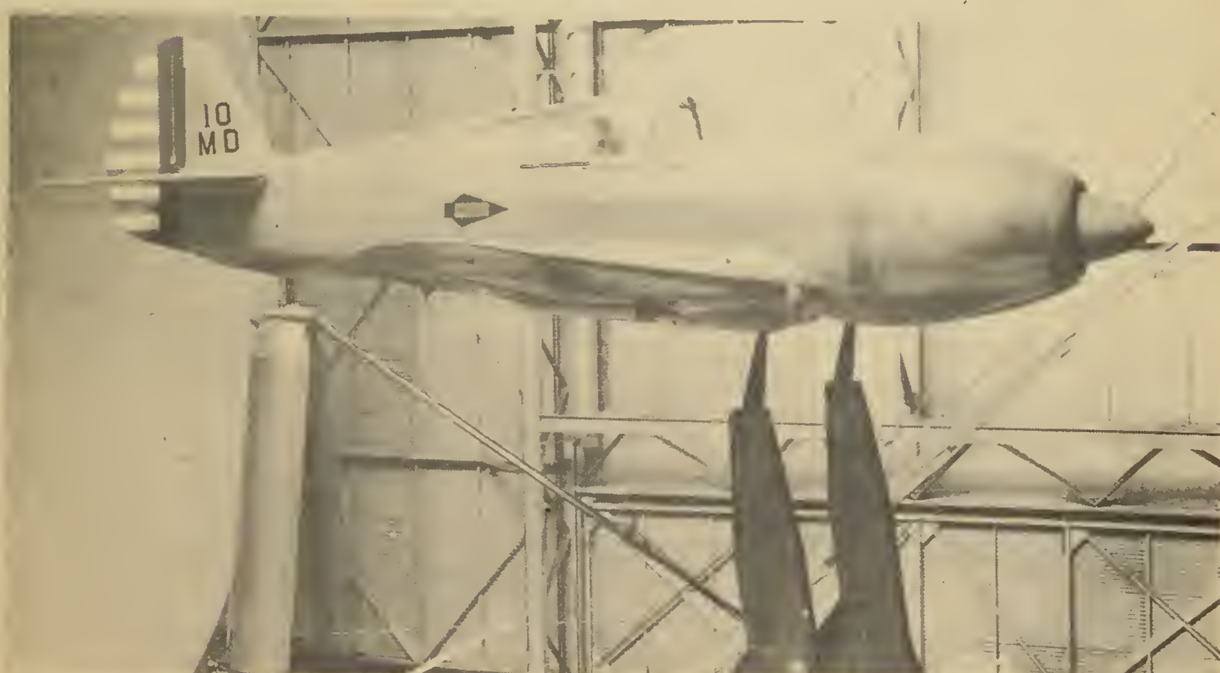


Figure 14.- The XP-42 airplane in the smooth condition with cowl 2 modified and smooth cowl flaps.

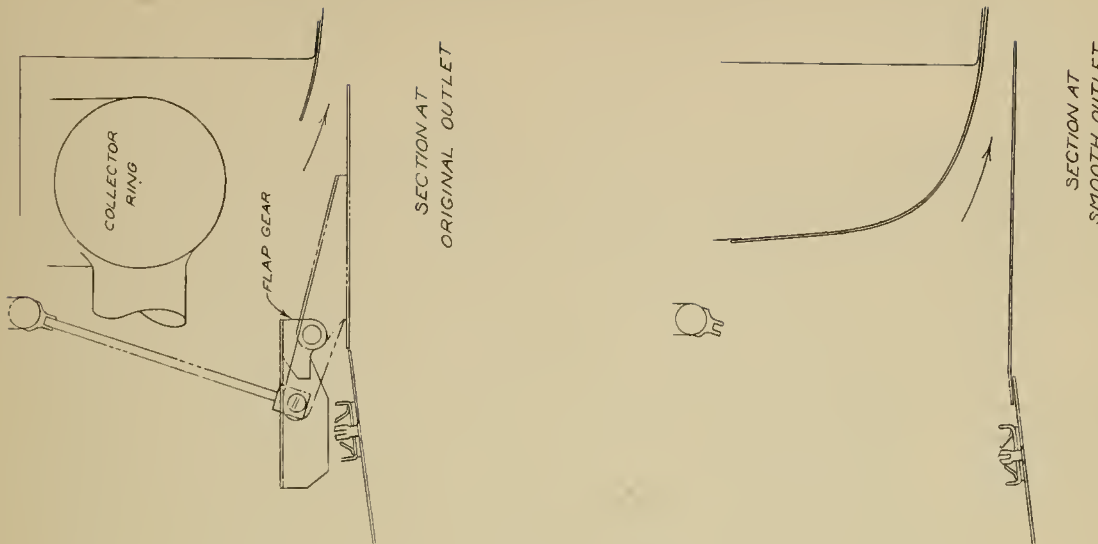


Figure 10.- Cowling outlets.

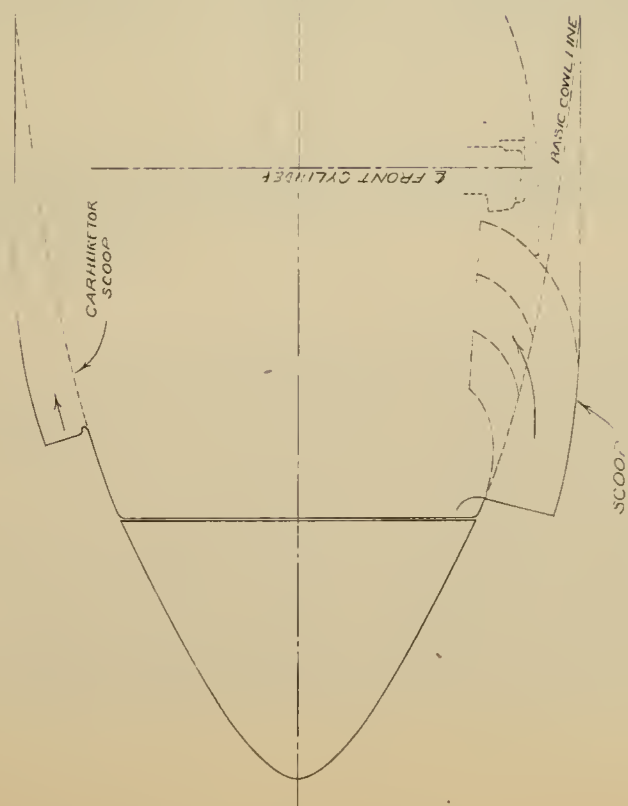


Figure 2.- Sketch of original XP-42 cowling.

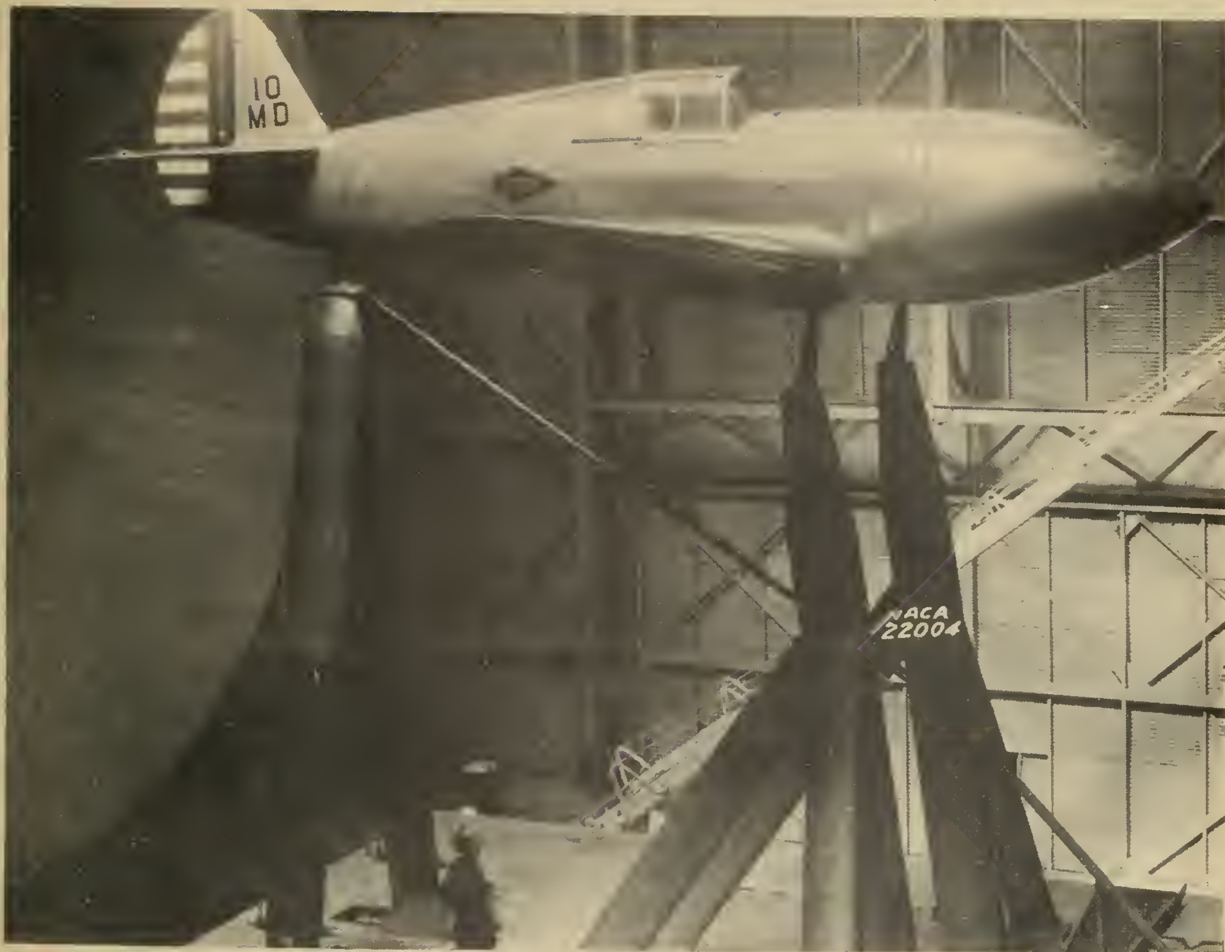
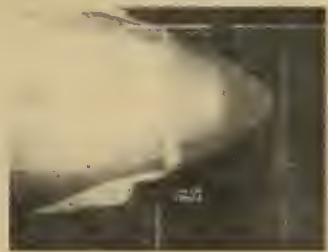
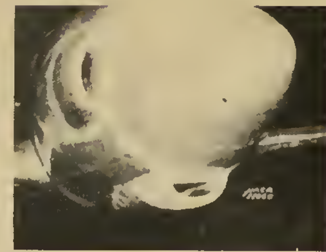


Figure 3.- The XP-42 airplane in the completely smooth condition mounted in the full-scale tunnel.

Figure 4.- The XP-42 airplane in the smooth condition with cowl 1 and original cowl flaps.

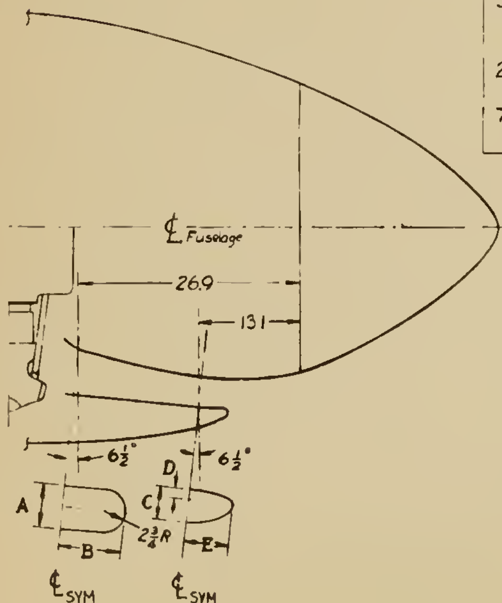

(a)

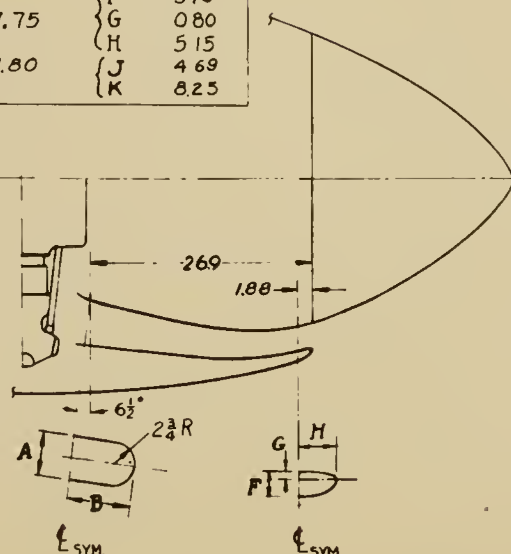

(b)

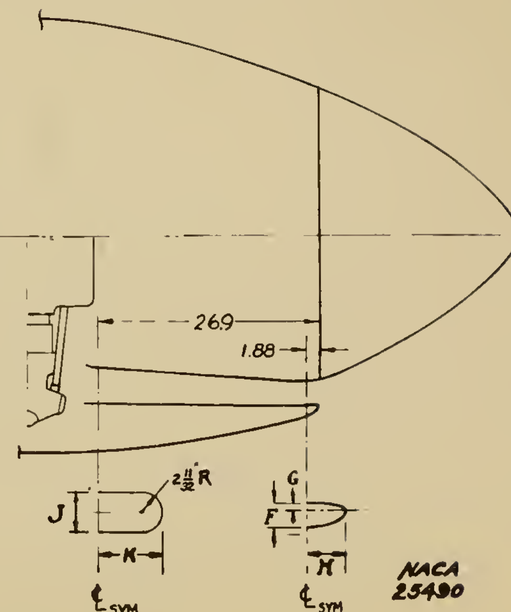

(c)

Section Area, sq in		Dimension, in
84.25	A	5.50
	B	8.25
39.00	C	4.00
	D	1.30
	E	5.95
27.75	F	3.13
	G	0.80
	H	5.15
71.80	J	4.69
	K	8.25

Fig. 5. - Cowl 1 and its modifications.







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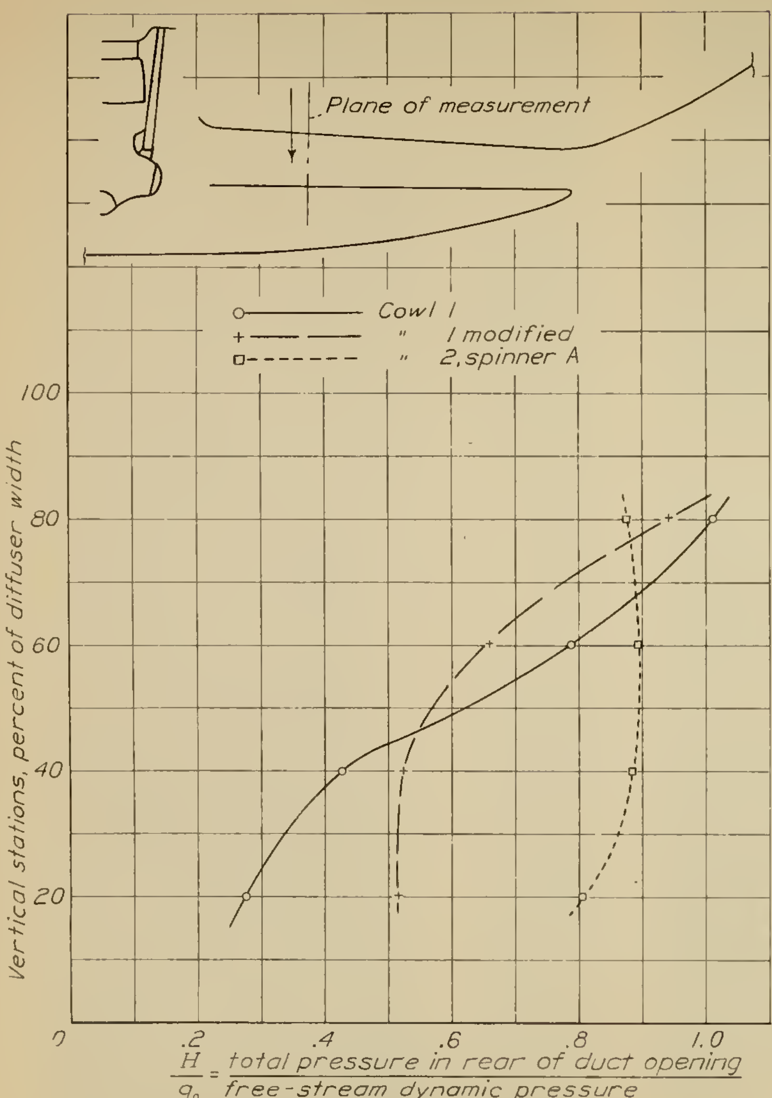


Figure 6.- Pressure in inlet diffuser.

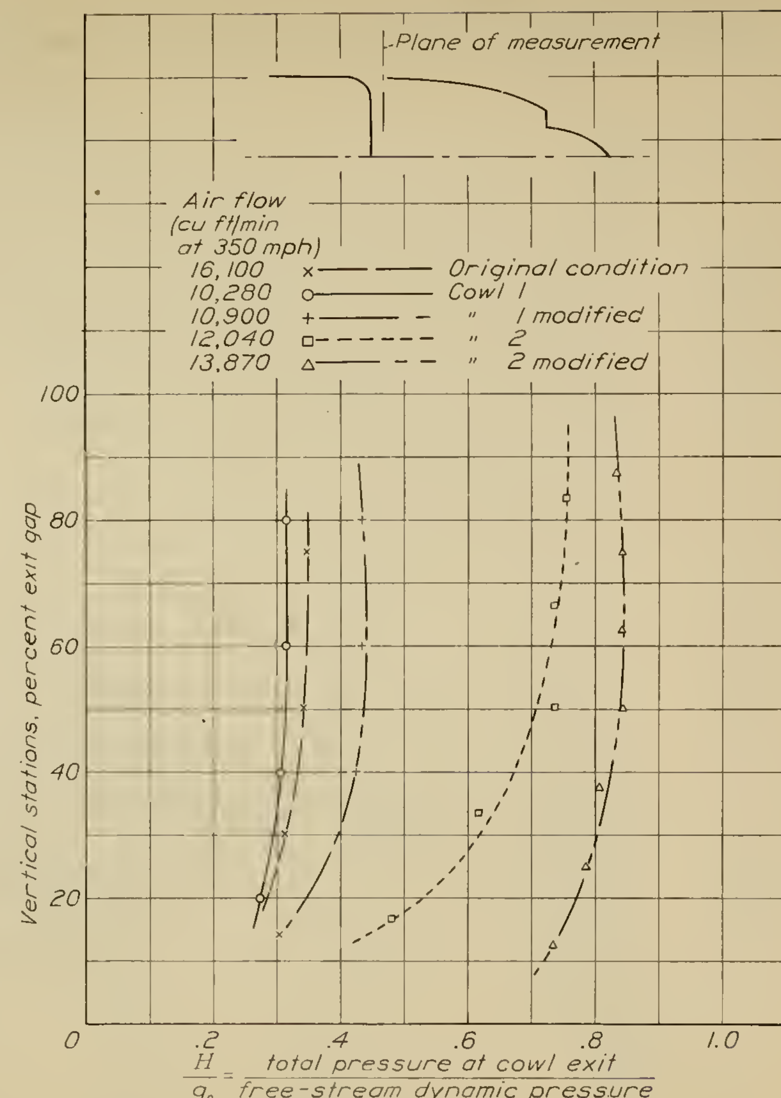


Figure 17.- Cowling outlet pressures.

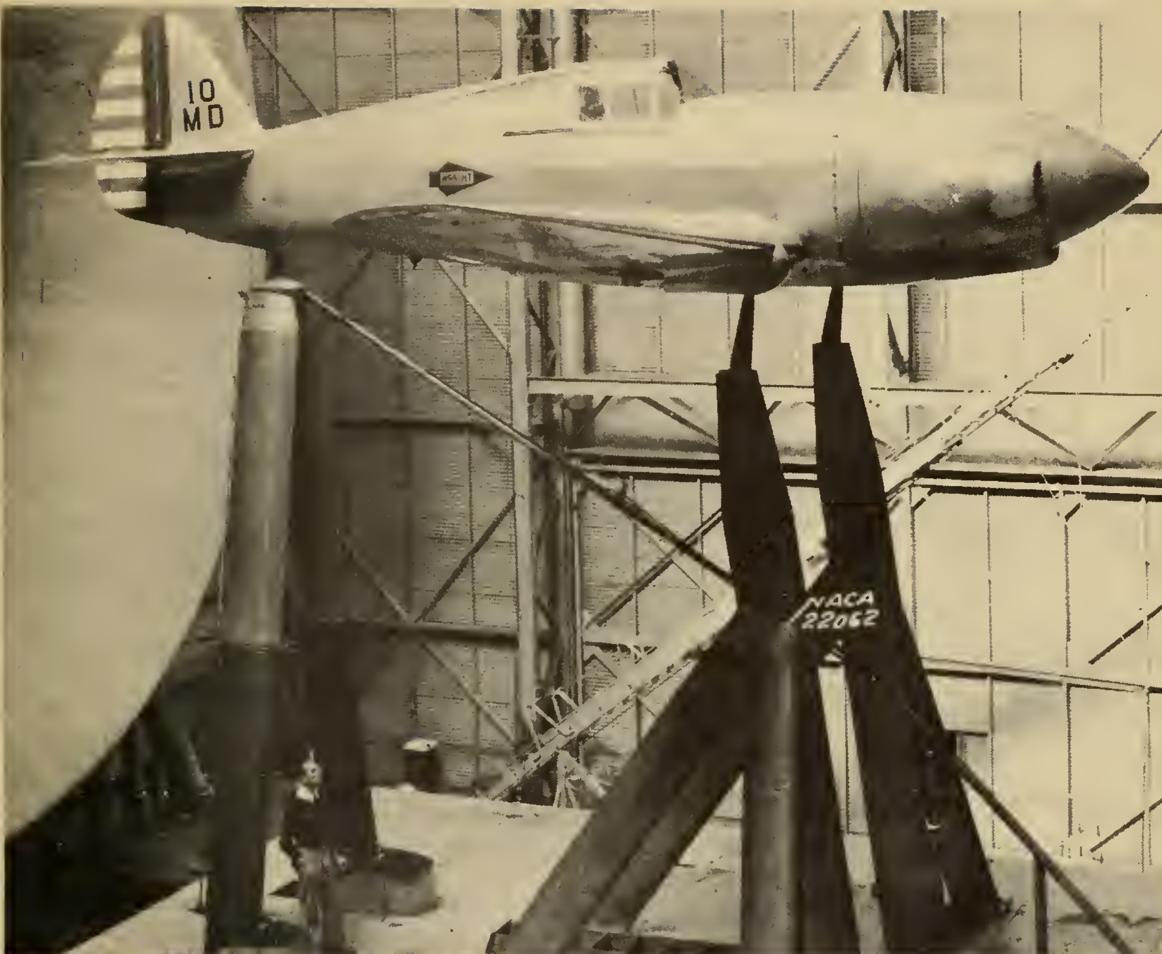


Figure 7.- The XP-42 airplane in the smooth condition with cowl 1 modified and original cowl flaps.

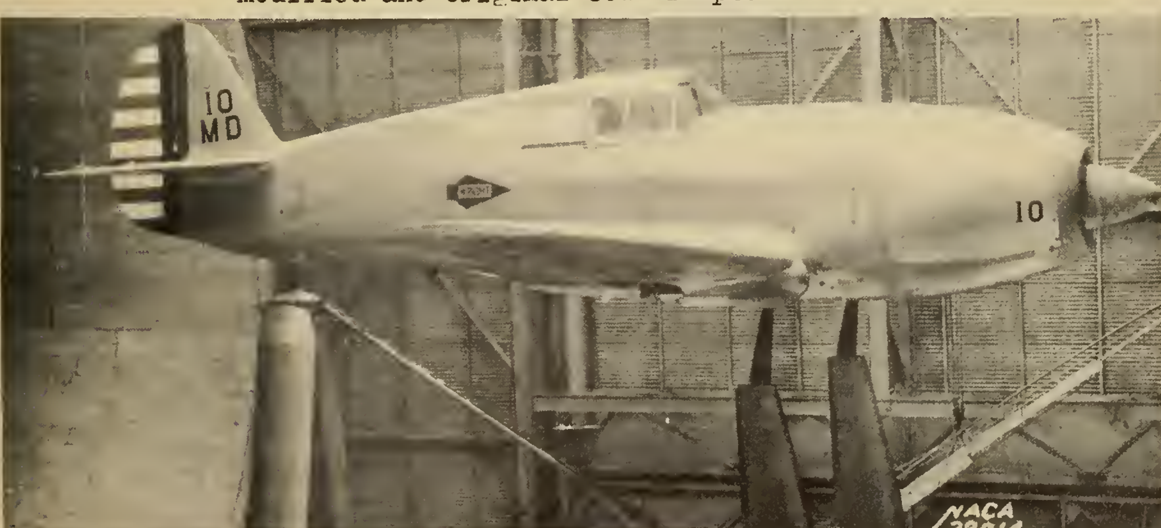
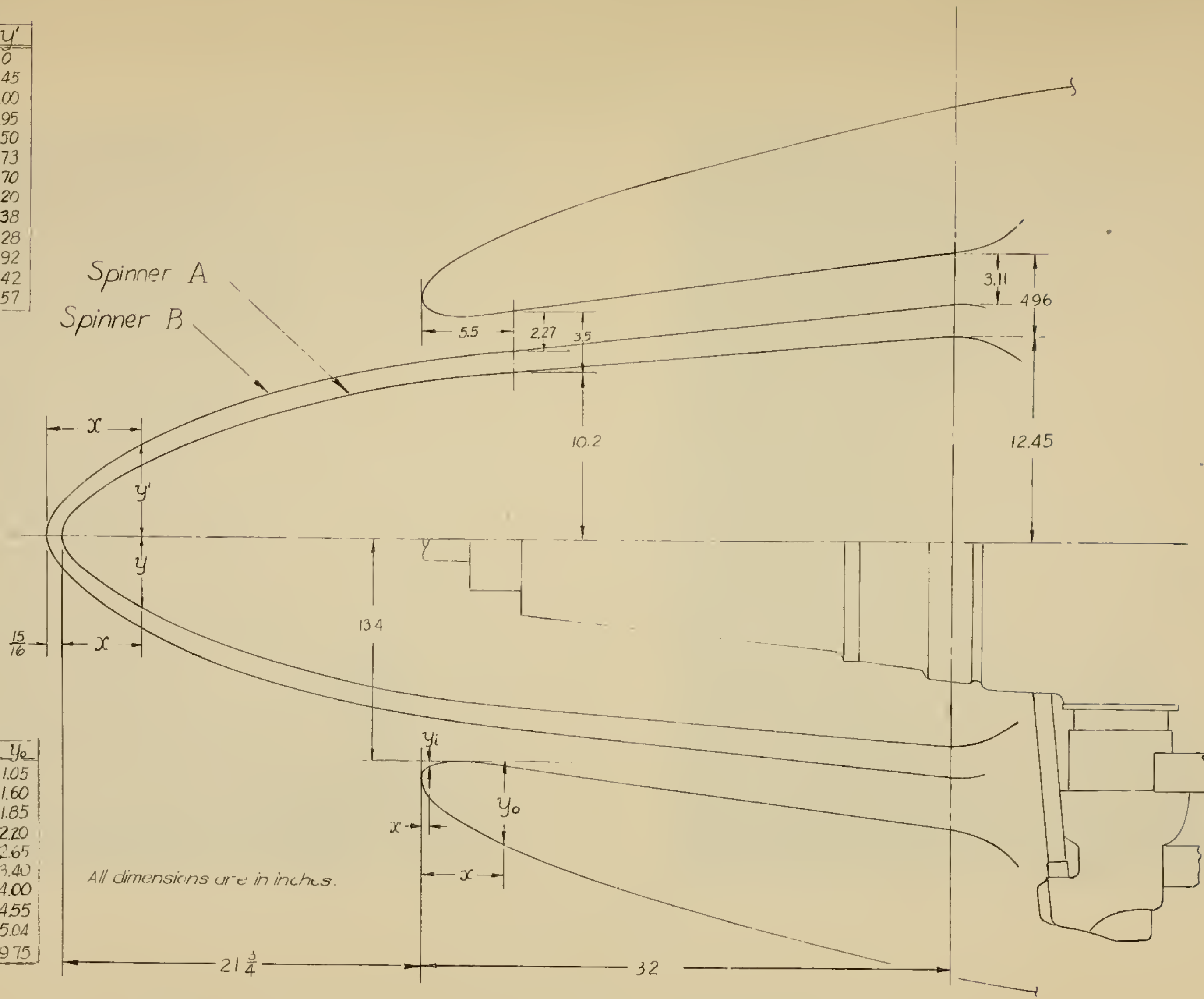


Figure 8.- The XP-42 airplane in the smooth condition with cowl 2, spinner A, and original cowl flaps.

Spinners

x	y	y'
0	0	0
5	1.20	1.45
1	1.72	2.00
2	2.49	2.95
4	3.85	4.50
6	4.93	5.73
8	5.80	6.70
12	7.21	8.20
16	8.33	9.38
20	9.20	10.28
24	9.80	10.92
28	10.22	11.42
48	11.97	13.57



Cowl

x	y_i	y_o
0	1.05	1.05
.125	.65	1.60
.25	.50	1.85
.50	.32	2.20
1.0	.12	2.65
2.0	0	3.40
3.0	.04	4.00
4.0	.13	4.55
5.0	.30	5.04
20.0	2.35	9.75

All dimensions are in inches.

Figure 9.- Annular inlet cowling number 2 with spinners A and B.

(a) Bottom outlet

(b) Modified bottom outlet

Figure 11.- Cowl outlet on XP-42 airplane.

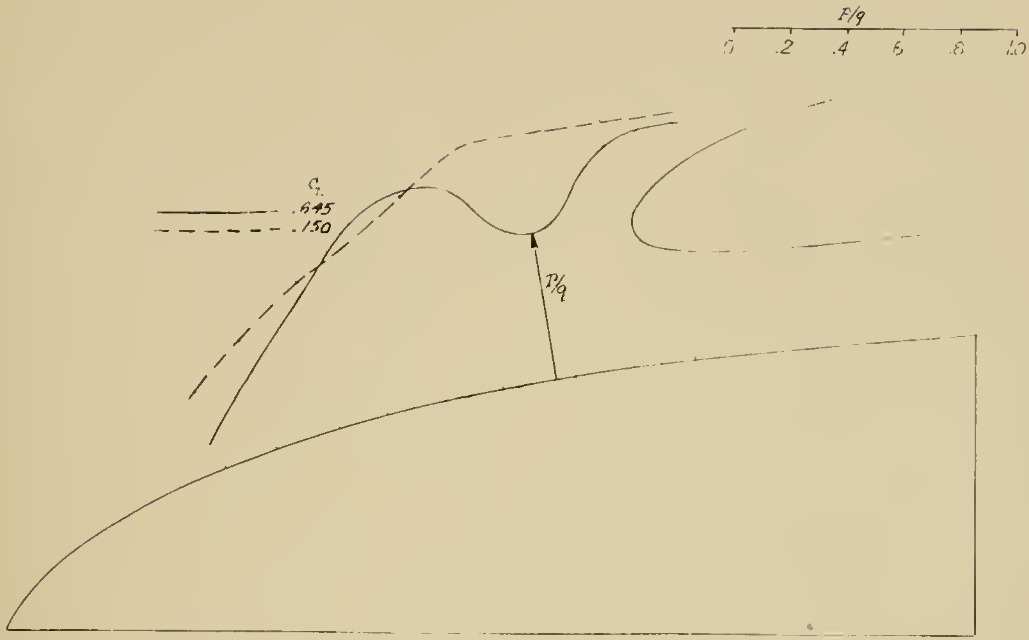


Figure 12.- Pressure distribution over top of spinner A with inlet velocity ratio V_i/V 0.32.

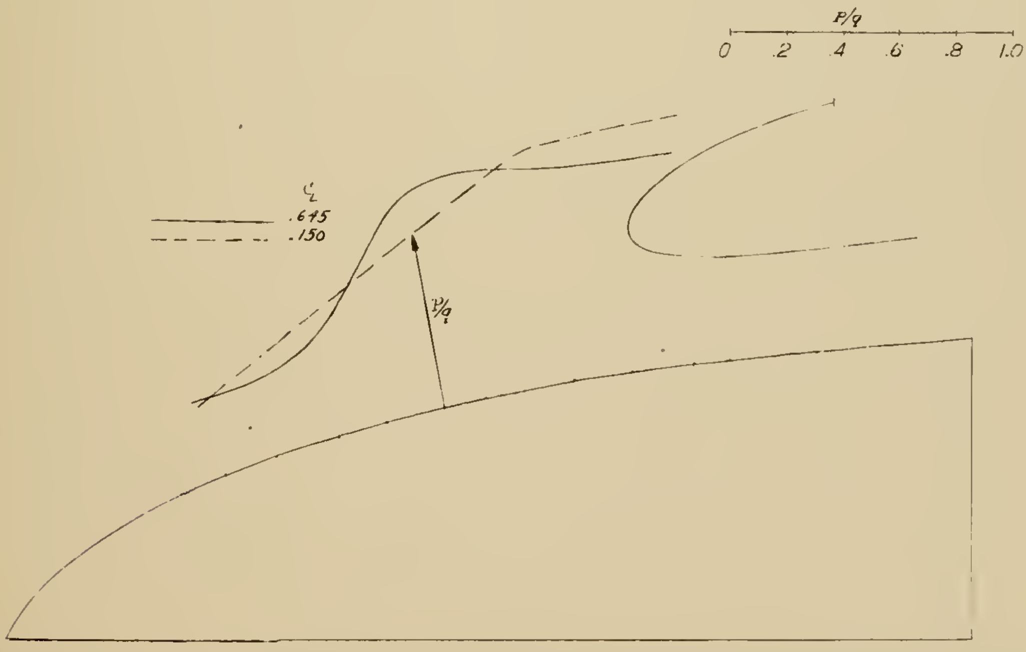


Figure 13.- Pressure distribution over top of spinner A with inlet velocity ratio V_i/V 0.49.

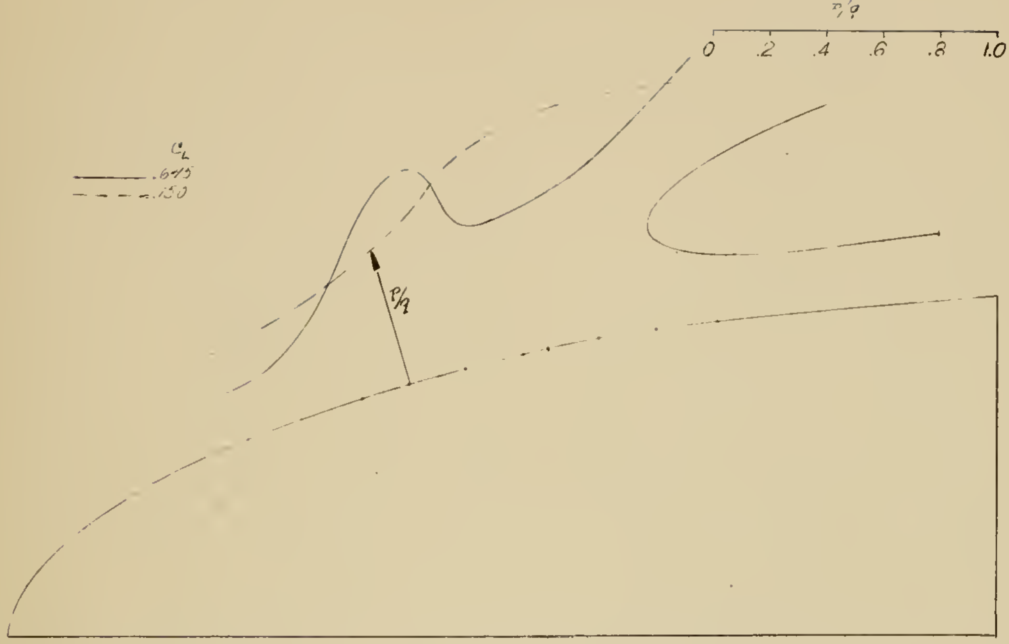


Figure 15.- Pressure distribution over top of spinner B with inlet velocity ratio V_i/V=0.55.

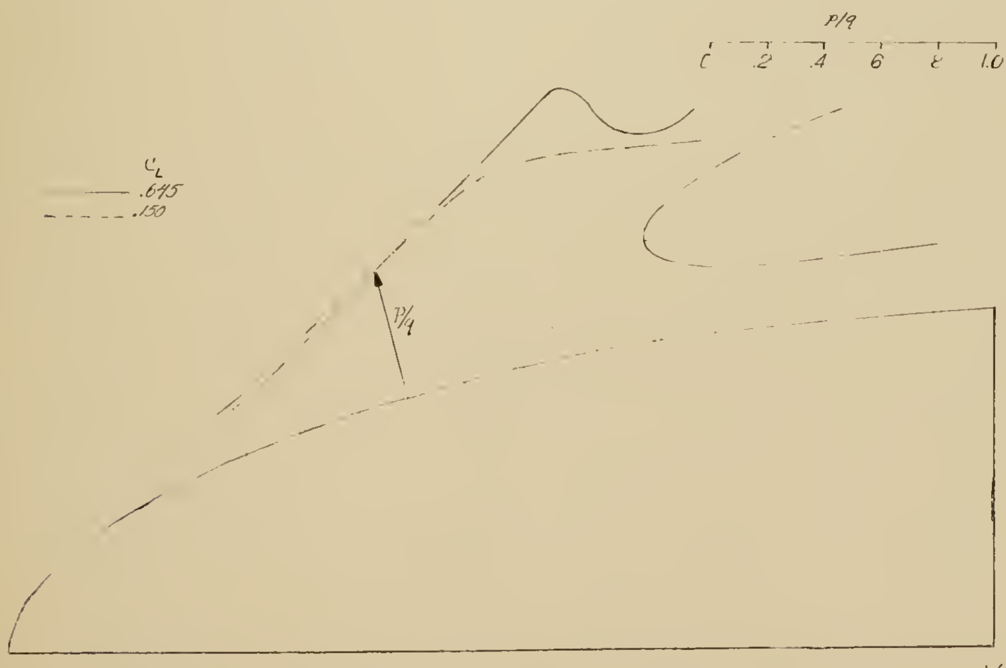


Figure 16.- Pressure distribution over top of spinner B with inlet velocity ratio V_i/V=0.83.

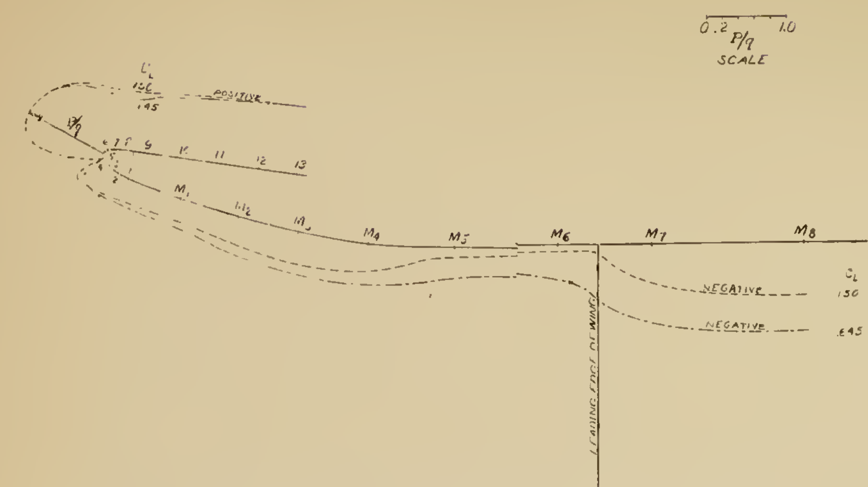


Figure 18.- Pressure distribution over side of cowl 2 with inlet velocity ratio V_i/V = 0.32.

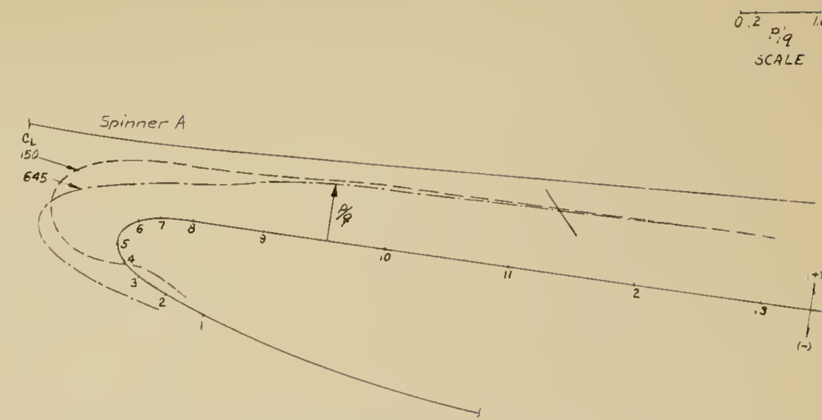


Figure 19.- Pressure distribution over bottom of cowl 2 with inlet velocity ratio V_i/V = 0.32.

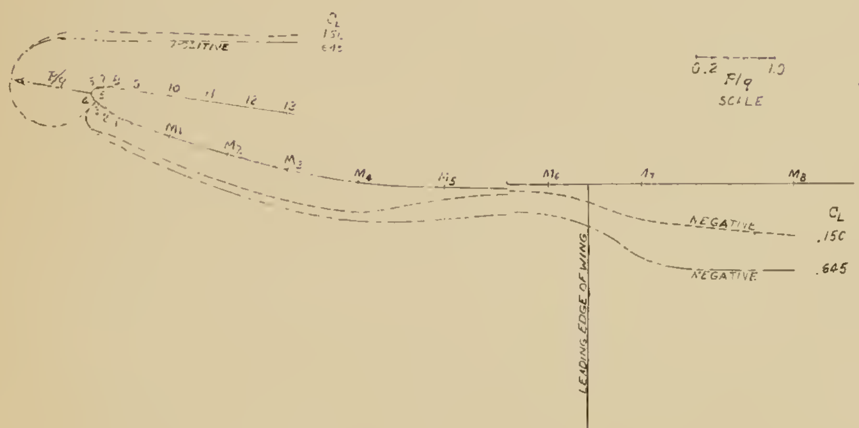


Figure 20.- Pressure distribution over side of cowl 2 with inlet velocity ratio V_i/V = 0.44.

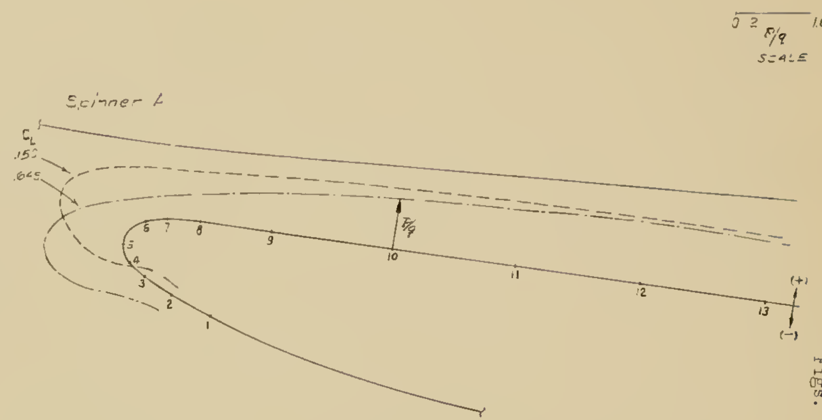


Figure 21.- Pressure distribution over bottom of cowl 2 with inlet velocity ratio V_i/V = 0.44.